An Extremely High I_{sp} Spacecraft Propulsion System

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Abstract. Specific Impulse, I_{sp}, is a measure of a rocket engine's efficiency. It is calculated relative to the Earth's gravitational field, where $I_{sp} = v_e / g_o$, with $g_o = 9.8\ m/s^2$ and the escape velocity of the propellant, v_e, in *m/s*. Chemical rockets have $v_e < 4.4x10^3\ m/s$ and $I_{sp} < 450$ *seconds*. As an alternative, the NASA Glenn Research Center developed multiple generations of Solar Electric Propulsion (SEP), high I_{sp} ion engines using Xe gas as a propellant. Consequently, over 100 SEP Ion Thrusters provide geo-synchronous station keeping along with deep space probes like Deep Space One and Dawn. These have $v_e \approx 2.9 \times 10^4$ m/s with $I_{sp} = 3x10^3$ *seconds.* These thrusters have continuous operating lifetimes of thousands of hours allowing continuous acceleration making up for the very low thrust.

Chang-Diaz' Variable Specific Impulse Magnetoplasma Rocket (VASIMR) has the potential for four times the propellant escape velocity and four times the specific impulse[1]. Unfortunately, this comes at a tremendous electrical power cost, estimated at 200 kW_e for maintaining the International Space Station in Low Earth Orbit (LEO). Although nuclear fission and fusion reactors[2] have been suggested for powering nuclear thermal propulsion (NTP) it only doubles the I_{sp} over chemical rockets but with comparable thrust.

Instead, we propose using Lattice Confinement Fusion (LCF) reactions.[3,4] Fig. 1 demonstrates multiple charged particles' fluxes and energies observed during LCF.[5,6] The reactions include:

- $D(^3He,p)\alpha$ with a 14.8 MeV proton and a 3.4 MeV alpha
- $Pd(d,n)p$ with a 6 MeV proton
- $^7Li(p,\alpha)\alpha$ with two 8.5 MeV alphas

where *D* and *d* are deuterons; *Li* are lithium atoms; *p* are protons; ^3He is a helion; and α is an alpha particle or ^4He. These charged particle reaction products can be shaped by magnetic fields to provide propulsion and derive spacecraft energy through Magnetohydrodynamic (MHD)[7] interactions with the escaping plasma.

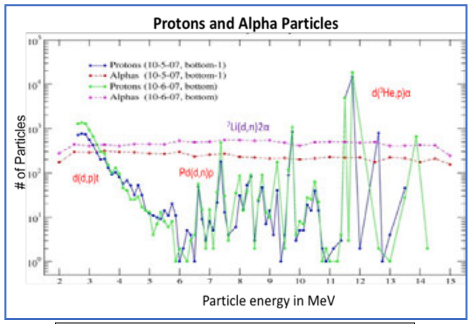

Figure 1 LCF alphas and protons

Alpha particles with over 6 MeV of kinetic energy have escape velocities approaching 5% *c*, (the speed of light, or $3x10^8$ m/sec), with $v_e > 1.5x10^7\ m/sec$ and comparably these particles would have $I_{sp} > 10^6$ *seconds*. This upper limit doesn't take into account plasma collisional losses or MHD losses in powering the reaction. As with ion engines, the proton and helium nuclei have small masses compared to the chemical rocket combustion products. However, additional mass, such as ammonia (NH_3) or hydrocarbon chains [$(CH_2)_n$] can be vaporized and expelled at the expense of velocity but with increased momentum transfer. An LCF charged particle, ion propulsion system, would have 500 times the I_{sp} of a conventional ion engine and 120 times VASIMR. In conclusion, an LCF nuclear reactor provides both extremely high I_{sp} propulsion and spacecraft power.

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